NSNS RING and TRANSFER LINES CONTROL SYSTEM

BNL/NSNS TECHNICAL NOTE

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NSNS Introduction

The NSNS Control system will be based on EPICS. The architecture of the control system is described in the System Design Integrated Control System description. It will be a standard two level system with Operator workstations communicating with front end computers, referred to as FEC by BNL and IOC in Epics. This note covers the HEBT, Ring and RTBT areas.

The purpose of the control system is to provide tools to the operator that make it easy to operate the facility. Operation entails commissioning, maintenance, studies, failure detection and data analysis as well as normal beam operations. Most of the tools needed to run a standard accelerator are well known. Functions like alarm processing, save/restore, data archiving, etc. are considered standard and will be included. Many of these tools will be modifications of programs running at other facilities using EPICS. It's expected that there will be a collaboration between labs to review EPICS software used at other facilities to determine which can be used in the NSNS control system.

For some subsystems the control interface is relatively standard, as for example the vacuum system. For diagnostic systems the hardware is unique, more data is collected and the analysis of the data will often depend upon the hardware or accelerator model. The NSNS has a large number of diagnostic devices and a good portion of the control system is devoted to processing the data collected from these devices

For the NSNS Beam Permit hardware will be installed to protect the hardware and limit radiation. The hardware will disable injection whenever a hardware error, excess radiation or other unusual conditions are detected. To help determine the cause of beam aborts, IOC's will save the last few seconds of data prior to the abort in local buffers for fault analysis. The saved data can be tens of megabytes.

HEBT

The controls for HEBT are listed below.

Vacuum - A detailed description for the HEBT, Ring and RTBT is included in the Vacuum system description that follows.

Power Supplies -A detailed description of the controls for the HEBT power supplies is given in the Power Supply Controls description that follows

Collimators - Motor controls are needed to position the movable collimators. The system will have inner and outer limit switches to prevent movement outside of prescribed, position indicators for error checking and an ADC to measure the motor power supply. Accuracy requirements are on the order of 0.1 mm. Positioning is infrequent and fast motion is not a requirement. Presently it's estimated that two of the collimators in the HEBT will be movable. The others will be fixed in position.

Energy Compressor - The Energy Compressor hardware will be supplied by Los Alamos. The system is controlled by a low level RF system (estimated 170 channels) and a power supply (estimated 30 channels).

Injection – The injection system consists of eight ramped supplies and two DC supplies. It is described in detail in one of the following paragraphs.

Injection Beam Dump – The Injection beam dump will consist of quad supplies, current transformer and beam loss monitors. Details will be included in the diagnostic and power supply system descriptions.

Linac Beam Dump – The beam dump will consist of quad supplies, current transformer and beam loss monitors. Details will be included in the diagnostic and power supply system descriptions.
of cycle but that local requirements will be met by this system.

Diagnostics - The diagnostic equipment in the HEBT consists of the following. A more detailed description of the control requirements for these items is given in the diagnostic system description. Los Alamos will provide some of the diagnostics for the HEBT.

- Beam Loss Monitors
- Current Monitors
- Beam Position Monitors
- Wall Current Monitors
- Harp
- Bunch Shape Monitors
- Time of Flight Monitors
- Wire Scanners

RING

Ring controls are needed for the following systems.

Vacuum - The Vacuum equipment is listed below. Details of the vacuum controls will follow.

Power Supplies - The control details for the power supplies are given in a following section..

Collimator – It's assumed that the four Ring Collimators will be fixed in position and no controls except for temperature and flow control monitoring will be needed.

Real Time Data Link – The real time data link is a system for distributing global information to IOC in real time. It is used to distribute operating mode data to IOC's with guaranteed response time of a few milliseconds. The need for this system is to be determined. It is valuable in a complex system with many operating modes. This system is potential useful in the NSNS upgraded system.

Ring Timing Control – The ring will need a timing system for coordinating the tasks in the different IOC's. It's assumed that a global timing system will generate timing global timing signals such as start and end of cycle but that local requirements will be met by this system.

RF - There will be one RF system to control two cavities. The RF system will have on the order of 120 I/O channels as shown in the table below. These consist of ADC, Bit I/O and setpoint control. It will also have a Frequency Synthesizer, Fast Digitizer, PLC, MADC, Function Generator, Beam Permit and timing signals. The MADC board will be used to read and store slow analog signals for several seconds. The Fast Digitizer will be used to read signals at the RF rate of 1.2MHz. The PLC will be used for Bit I/O control. The Frequency Synthesizer will be used to set the RF Frequency. A beam dump signal will cause the last few seconds of data to be saved until read by the workstation. Function generators will produce two-millisecond waveforms at 60 Hz using a 100KHz or greater clock . Operator software will be available to generate, display and download waveform to the IOC's.

SYSTEM	# CHANNELS	READINGS PER PULSE	#PULSE[1]	TOTAL DATA
Frequency Synthesizer	12	1	10	12
MADC	32	1	200	6400
PLC	40[2]	1	10	400
Timing Signals	24	1	10	240
Bit I/O	32[2]	1	10	320
DAC	16	1	10	
Function Gen.	4	100		

[1] A history of setpoints will be kept so that readback changes can be correlated with command changes. Ten is expected to be sufficient. For readings data for the last 200 pulses is saved in a buffer. This number may change.

[2] This number is a total for readings and settings.

SYSTEM	# CHANNELS	READINGS PER PULSE	#PULSE[1]	TOTAL DATA
Fast Digitizer	8	1200	200	1,920,000
Total	**168**			**1,927,372**

Diagnostics - The diagnostics equipment in the HEBT consists of the following. A detailed description of the controls required for the Ring diagnostics is given in a following section.

- Beam Loss monitors.
- Fast Beam Loss Monitors
- Fast Beam Current Monitor
- Beam-In-Gap Monitor
- Beam Current monitor
- Beam position monitor
- Fractional Tune Measurement
- Beam Profile Monitor
- Beam Damper

RTBT/Extraction

The controls for HEBT are summarized below.

Vacuum - The Vacuum equipment is listed below. Vacuum control details will follow.

Power Supplies - The controls for the transport line power supplies are described below.

Collimators – The four collimators will be fixed devices with flow control and temperature monitoring.

Extraction Beam Dump – The extraction beam dump will consist of quad supplies, current transformer and beam loss monitors. Details will be described in the diagnostic and power supply descriptions.

Diagnostics - The diagnostics equipment in the RTBT consists of the following.

- Beam Loss monitors
- Current monitor
- Beam position monitor
- Harp
- Wire Scanners

INJECTION

For Injection, controls will be needed for the following equipment.

DC Power Supplies - There will be two orbit dump DC power supplies used for injection. The control for the Injection DC power supply is similar to the other transport line supplies. A PLC will be used for status monitoring and on/off control. The power supply current will be set and read by a VME power supply controller board.

Ramping Power Supplies - There will be eight ramping power supplies for injection. For the ramping supplies, PLC's will be used to monitor and control status and perform on/off control. Other VME hardware described below will generate ramping waveforms and read the power supply current at a high rate.

The hardware and software must be able to generate a coordinated one-millisecond ramp synced to injection for all eight ramping supplies. VME hardware is available from the NSLS that does this function. After downloading a function to the board and issuing a start pulse, the desired waveform will be generated. The placement of the waveform generators is a function of the distance between the power supplies and VME hardware. If the distances are not short the waveform generators will be near to or be an integral part of the power supplies. A local bus will be needed to download the waveform generators. This could be a VME bus repeater, GPIB or other bus. Commercial waveform generators are also a possible solution. An adaptation of the power supply controller with fiber optic interface will also be considered. Thirteen bits of resolution for the power supply setpoint is adequate.

The IOC will use a fast ADC to read the current during the ramp. A rate of 200KHz will give 200 samples during the millisecond pulse. A multi-channel digitizer will be used in several of the diagnostic systems. One of the same types will be used to read the Injection supplies.

The IOC will save the data from consecutive pulses for several seconds. On a beam permit interrupt or other error condition the data will be stored for fault analysis.

Workstation software to let the operator generate and down load ramps and to read and plot the current versus time will be available. Also software to display the difference between the specified ramp and current readbacks, the difference between successive readings or the difference between readings and a reference data set will be provided.

Injection Dump Line – The Injection Dump line will have two quad supplies.

Power Supplies	#	#Signals	Table Size Waveform	Table Size Readings	Resolution	**Total**
Ramping Supplies	8	25			13	**200**
- Setpoint Waveform	8		200		13	**1,600**
- Readback Waveform (100kHz digitizer)	8	120(2sec.)		200[3]	14	**192,000**
DC Supply, b3,b3a,b4a	3	25			15	**75**
Quads, Dump line	2	25			15	**50**
Correctors, dump line	2	15			14	**30**
Total						**193,955**

Stripping Foil

It's planned to change the Foil manually. The computer will be used to monitor the foil position.

[3] Data is saved in a buffer for analysis no beam dumps or other errors. Two hundred pulses or just over three seconds of data is saved. This number may be reduced or increased as necessary.

Vacuum

For each of the areas, HEBT, RING and RTBT, the type of equipment, the number of units to be controlled and an estimate of the number of devices is given in the table below.

For the Vacuum system, most of the hardware control will be done with Programmable Logic Controllers (PLC's). The Vacuum group will purchase hardware (gauges, pumps, valves etc.) that have an interface compatible with PLC's. Sequencing and error detection logic can be done by a PLC. There are no requirements for fast updates or fast logic. Two Hertz data acquisition is adequate.

The Vacuum IOC will contain the standard components, VME crate, CPU, Utility module, memory board etc. It will also have a PLC interface board to control the hardware and a Beam Permit board. The Beam Permit System will allow the Vacuum hardware or the IOC to disable the beam if one of the vacuum valves close, vacuum exceeds limits or any other condition that would cause excess radiation or damage to equipment.

The IOC will generate alarms if an error is detected. The only alarm needing a reasonably fast response is Sector Valve Closed errors. Errors in other devices will generate lower priority alarms.

Software Requirements

Besides the standard software to set and read parameters, archive data, save and restore parameters etc, the following software will be needed.

- Provide a graphical display of Vacuum versus Pump location.
- Provide for displaying archived data in a graphical format.
- Recognizing, reporting and saving to disk all alarm data.
- Monitoring for illegal conditions that prevent injection.

VACUUM DATA

HEBT DEVICE LIST

Equipment	# Items	#Channels per Item	**Total Channels**	Total Log Points
Sector Valves	6	3	18	6
Ion Pumps	13	5	65	13
Roughing Pumps	4	8	32	4
CC Gauges	8	6	48	8
TC Gauges	5	4	20	5
Total	**36**		**183**	**36**

RTBT DEVICE LIST

Equipment	#Items	#Channels per Item	**Total Channels**	Total Log Points
Sector Valves	7	3	21	7
Ion Pumps	17	5	85	17
Roughing Pumps	6	8	48	6
CC Gauges	12	6	72	12
TC Gauges	7	4	28	7
Total	**49**		**254**	**49**

RING DEVICE LIST

Equipment	#Items	#Channels per Item	**Total Channels**	Total Log Points
Sector Valves	8	3	24	8
Ion Pumps	64	5	320	64
Roughing Pumps	8	8	64	8
CC Gauges	16	6	96	16
TC Gauges	8	4	32	8
Total	**104**		**536**	**104**

Power Supplies

Most of the power supplies in the NSNS will be DC supplies. The exceptions are a few injection supplies, which are fast ramping supplies, described in the injection system, and the fast Kicker. The supplies for the RING, HEBT and RTBT all have similar control requirements and are listed here.

The NSNS power supplies will have a standard interface to the control system. The goal is to minimize the number of interface definitions thus simplifying the programming, documentation, test procedures, etc. A fiber optic connection to a BNL power supply controller will be used to set the supply. The Power Supply will return the received data to the controller so the IOC can verify that the transmitted data was received correctly. Because of the fiber isolation, ground loops and noise problems that might be expected when sending analog signals over long distances are eliminated. The format of the digital data allows sending up to 24 bits of data so the same interface can be used for different resolution supplies. This type of interface is in use at RHIC. A modification of the RHIC power supply controller is planned for the NSNS. The present board has a waveform generation capability not required by the NSNS. This function may be useful for power supply conditioning. There may be reasons for keeping the functionality of the existing board.

A PLC will be used to send on/off commands and read the power supply status. It will also monitor interlocks and will inhibit the beam under unusual conditions.

The Power supply will also send an analog signal indicating current to a Multiplexed ADC (MADC) board in the IOC. The RHIC MADC board is described in the reference material. It can digitize signals from up to 64 supplies and store the data in a local buffer for postmortem dumps. Simultaneously with reading all channels at 720 Hz, it can read one selected channel at 50kHz or multiple channels at a reduced rate(2 channels at 25 kHz, etc.). This allows engineers to look at the ripple or noise on individual power supplies from any location for diagnostic purposes without interfering with normal operations. It also provides a means of locating spurious errors that cause loss of beam. Glitches in the power supplies or other electronics that can affect the beam are difficult to find without this type of monitoring. The MADC will continuously store data in a circular buffer until a halt command is received. A beam dump signal for example will halt further data collection until a restart command is issued. There is sufficient memory on the MADC to hold several seconds of data for all channels. The MADC receives data via the timing system indicating when recording of data should stop. Data saved in a buffer is time stamped.

In addition to the normal readbacks for the Dipole, a Hall Probe will be used to measure the field. A high precision (0.01%) Teslameters with fiber optic RS-232 or GPIB interface is an example of a device that may be used. For absolute reference an NMR probe will be used.

Power Supply Data

HEBT

Power Supplies*	Bipolar	Resolution	#Magnets	DC	#Supplies	Channels per Supply[4]	Total Channels
Dipole,7.5deg.	No	16 bits	1	yes	1	25	25
Dipole,7.5deg	No	16 bits	12	yes	1	25	25
Quads,laws	No	16 bits	8	yes	4	25	100
Quads,acro	No	16 bits	12	yes	2	25	50
Quads,rms	No	16 bits	13	yes	9	25	225
Correctors	Yes	14 bits	33	yes	33	15	495
Quads, linac beam dump	No	16 bits	6	yes	4	25	100
Correctors, linac beam dump	Yes	14 bits	6	yes	6	15	90
Total			**91**		**60**		**1110**

*Dipoles, 5.9 & 1.56 are in injection line.

RING

Power Supply	Bipolar	Resolution	#Magnets	DC	# Supplies	Channels per Supply	Total Channels
Dipole	No	16	32	yes	1	25	25
Quads, Vert.	No	16	24	yes	1	25	25
Quads, Hor.	No	16	16	yes	2	25	50
Octupoles	?	14	8	yes	8	15	120
Correctors	Yes	14	96	yes	64	15	960
Total			**176**		**76**		**1180**

[4] The larger supplies will have 16 error/status bits, up to 3 analog readbacks, on/off control, reset and bus link status.
The smaller supplies will have fewer error/status bits.

RTBT

Power Supply	Bipolar	Resolution bits	#Magnets	DC	#Supplies	Channels per Supply	Total Channels
Dipole	No	16	3	yes	2	25	50
Kicker Magnet	No	16	1	yes	1	25	25*
Lambertson	No	16	1	yes	1	25	25
Quads	No	16	20	yes	20	25	500
Quads, special	No	16	5	yes	5	25	125
Correctors	Yes	14	30	yes	30	15	450
Quads, extraction beam dump	Yes	15	2	Yes	2	25	50
Correctors, extraction dump	Yes	14	2	Yes	2	15	30
Octupole	No	15	2	Yes	2	15	30
Total			**67**		**66**		**1,290**

* Timing Trigger Required

Diagnostic Data

System	#Supplies	Samples/Sec.[5]	#Seconds[6]	Total Data[7]	Total Data[8]
HEBT	56	500	3-100	84,000	2,800,000
RING	76	500	3-100	114,000	3,800,000
RTBT	94	500	3-100	141,000	4,700,000
Total	**195**			**292,000**	**9,750,000**

Diagnostic data is data that is read by the IOC hardware for fault analysis after a beam dump or other failure. The current will be read at approximately 500 Hz and the last 3 seconds of data will be kept in memory

Maintenance Data[9]

System	#Supplies	#Samples/Supply[10]	Total
HEBT	56	1000	56,000
RING	76	1000	76,000
RTBT	63	1000	63,000
Total	**195**		**195,000**

[5] The data rate will depend upon engineering requirements and may range from 10 to 750 Hz.
[6] Data will be saved for a duration that depends upon the type of errors that are anticipated and may range from 3 to several hundred seconds.
[7] Total Data assuming data is saved for three seconds.
[8] Total data assuming data is saved for 100 seconds. Total data may be limited by local data storage which typically will be up to 4 Mbyte per MADC board..
[9] This is the high speed reading of data by multiplexing selected signals to high speed ADC's. It is used to look for out-of-spec conditions.
[10] Samples-per-second is a variable that may range from 50 to 50,000Hz. The sampling rate and time duration is set to acquire the number of samples needed for the analysis.

Maintenance data is data read on demand to check the condition of the hardware. In this case each power supply can be read at a high rate to check ripple etc.

Diagnostics

There will be diagnostic hardware in the HEBT, Ring and RTBT. Because of the different beam characteristics the electronics and processing requirements for each area are different. In the HEBT the beam will be a constant current millisecond pulse. In the Ring, the beam will be a varying current pulse one millisecond in duration. In the RTBT, the beam pulse will be a one half microsecond. A detailed description of the Ring diagnostic system is given below.

Ring Diagnostics

A description of the diagnostic systems for the Ring is given in NSNS Technical Note 17, NSNS Beam Diagnostic Instrumentation. The control system requirements for each system are given below.

The physical configuration of the equipment buildings determines where the electronics are placed which in turn determines the modularity of systems and thus the number of Front End Computers.

The diagnostic instrumentation will use several types of fast ADC's or Transient Digital Recorders (TDR's). They are designated Transient Digital Recorder (TDR), Fast TDR (FTDR) and Very Fast TDR (FTDR). The first is a multi-channel device capable of sampling each channel at 100KHz and memory sufficient to hold several seconds of data per channel. These will be used in the HEBT and Ring where it's necessary to read the data many times during the pulse. The FTDR'S will have a 1.2 MHz sampling rate and are used to take a measurement on each bunch in the pulse. These are used in the ring Fast Beam Loss Monitor systems. The VFTDR will have a sampling rate of at least 1GHz and will be used where the detailed structure of each bunch is wanted. Depending upon the requirements one or more of these digitizers will be used in each of the diagnostic systems described below.

The VFTDR will be a commercial device. It will be used where a single sample at high resolution is needed. The slower TDR's must save data at a high rate in local memory for several seconds while simultaneously providing a subset of the data to the computer on request. Commercial boards do not usually have this feature. One solution is to use a combination of software and hardware. The fast sampling hardware gets the data, gives it to the computer which saves the data in a circular buffer. At BNL, a fast ADC VME board with sampling rates as high as 5 MHz. per channel and on board memory for each channel is being developed. The board has programmable nanosecond timing triggers for each channel therefore it would be suitable for measuring individual bunch data. A dedicated processor, either DSP or second VME CPU will be needed to preprocess the data from TDR's and FTDR's.

Because the NSNS current varies linearly with time, the diagnostic measurement equipment must operate over a large dynamic range. In some cases, the analog electronics will vary the gain during the pulse. The computer must write a gain versus time table and the electronics will apply it when measurement starts.

To measure data on each bunch very accurate (nanosecond) signals are required. Some electronics (BPM) will need triggers synchronized to the RF with nanosecond resolution to measure bunch amplitude.

The initial plan was to have four equipment buildings, one on each side of the Ring to service devices in that quadrant. It's possible that this will be changed and there will be one building in the center of the Ring.

Beam Loss Monitor.

The Beam Loss Monitors will monitor beam loss by measuring the radiation at intervals around the ring. There will be eighty(80) monitors distributed around the ring, grouped approximately twenty (20) per quadrant. The result will be one IOC per area, or a total of four IOC's. One CPU per VME is assumed but an alternative configuration is to have the crates linked by a shared memory bus. The large amount of data to be collected will probably make the one CPU per system the better choice.

The Beam Loss Monitors will use a TDR to sample the data on each pulse at a 100khz rate. This will give 100 samples during the millisecond pulse. The IOC will save several seconds worth of data in memory so it's available for beam dump analysis when failures occur. The data needs to be time stamped so that measurements from all IOC's can be correlated when read by a host computer. .

This system requires two triggers, one indicating the start of pulse and a second from the Beam Permit system. When the Beam Permit System indicates a beam dump has occurred, updates will stop and the previous few seconds of beam loss data is saved to a buffer

The data per FEC is 100 samples per pulse, 20 channels per crate, 60 samples per sec, 2 bytes per sample or an average rate of 240k bytes per second per IOC. This could be higher since there may not be an even distribution of monitors on all quadrants. Four megabytes of memory is sufficient to store data for many seconds.

Total data collected (80 BPM's, 100 samples/pulse, 200 pulses or 3.2sec.) will be 1,600,000 samples exclusive of time stamps.

The local electronics will use a Bit I/O interface to read and set the status and gain of each channel. This system will generate interrupts on excess beam loss. There will be bits for each channel indicating alarm or error conditions. It will be necessary to set the alarm trip points for each channel. One option is to use a multi-channel VME DAC board but it may require running analog signals long distances. A second option is to place the DAC in the local equipment and use a local bus or Bit I/O to set the DAC's..

Software will be needed to display the beam loss as a function of location around the ring for a particular sample time, the pulse to pulse change in beam loss and beam loss versus time for any particular monitor or set of monitors.

Fast Beam Loss Monitors

Eight Scintillator-Photomultipliers will be located in critical areas around the Ring to give more detailed information on beam loss. The exact location around the Ring has not been defined but there will be from one to four systems per quadrant. The control requirements for this system is similar to the slower beam loss monitors except that the ADCs must take a measurement on each bunch which means the sampling rate is increased to 1.2Mhz. per channel. The hardware will require both a start signal and a trigger from the RF indicating the presence of each bunch..

The preprocessing electronics must process signals over a large dynamic range. Like the Beam Loss Monitors, it must vary the signal gain as a function of time. The gain table will be set and read by the computer. Sampling of the data at the correct time will require setting time delays very accurately and the delay for each channel will be adjustable by the computer.

By sampling at 1.2 MHz. the total samples per second per monitor is 72,000. The maximum number of monitors per crate is four, so the maximum sampling rate is 288kHz. From a memory storage standpoint this is still a low number. The data transfer rate between ADC and memory is approximately 1MHz which is well within the VME bus bandwidth specifications.

For more detailed information on beam loss, any one of the BPM signals can be switched to a VFTDR and sampled at rates up to 1GHZ. Each of the BPM signals will go to both a FTDR(1.2MHz) and to a multiplexor controlled by the IOC. The multiplexor output will be input to the VFTDR.

The IOC will monitor the status bits from local electronics. The photomultiplier high voltage will also be controllable by the IOC.

The monitors will be placed in strategic locations near injection and extraction points. The software will display the beam loss versus time. The software needed to support studies is yet to be determined.

Data - 1200 samples/pulse, 200 pulses, 8 devices = 1,920,000 samples

Diagnostic Data – The sampling rate will be 100MHz. The duration of the sampling is yet to be determined.

Beam Current Monitor

There will be one Beam Current Monitor using a Beam Current Transformer. The interface to this system is similar to the requirements for the Beam Loss Monitors. It will require one high speed (100kHz.)Digitizer channel. The software will provide the option of reading the peak current or the entire waveform. Measuring current, normally a simple matter, is more complicated because the current versus time waveform is needed and this requires many measurements of a gain compensated signal over the pulse.

The requirements for gain control and status monitoring in the Beam Loss system will apply to this system.

Data - 100 samples pulse. 200 pulses = 20,000 measurements

Other - Gain control. status monitoring.

Fast Current Monitor

The fast beam current monitor will measure the time history of the charge within the bunch.. The hardware for this system will sample the data at a very high rate, up to 1GHz. The control system must be able to setup the digitizer and make measurements on request of the operator. The amount of data collected will be determined by the hardware setup.

Special operator software will be needed for this system. The data acquired will be a function of the settings for the VFTDR. It will be necessary to read the digitizer parameters and normalize the data before processing and presentation. The analog processing hardware will have an interface similar to the other systems.

Bit I/O will be needed to read and set Gain or status bits.

Beam In Gap (BIG) Monitor

Several options are being considered for Beam In Gap monitoring. Its expected that from the controls standpoint this system will be similar to other systems requiring a 100Mhz sampling rate. The setup and monitoring of analog electronics by the IOC will be necessary.

One reading is 100,000 measurements.

Beam Position Monitor

The Beam Position system will have dual plane monitors at 48 locations distributed around the ring. The total number of channels is 96. The preprocessing electronics will have gain switching to provide the large dynamic range required. A fast digitizer (1.2Mhz) will be used to measure the beam position for each bunch. This provides 1200 samples per pulse. The system will have sufficient memory to save about two seconds of data. The total saved data could exceed 20 Mbytes and will be used to help determine the cause of beam dumps. Failures that disable the beam permit system will inhibit further sampling until the buffered data is saved.

I/O boards to set and monitor the state of the electronics and to set the channel gain will be needed. There will be separate timing control for each channel under program control.

Selected channels of the BPM will go to a multiplexor where they can be routed to a VFTDR.

Data - 96 channels, 1000 samples/pulse, 200 pulse buffer = approximately 20 Mbytes.

Fractional Tune Measurement

The Fractional Tune Measurement is accomplished by kicking the beam and measuring the beam motion a quarter wavelength downstream of the kicker magnets. This system will consist of two racks of equipment including one IOC. The control system must set and monitor the kicker magnets while reading one or more BPM's around the Ring. The data will be collected by a VFTDR (1Ghz) and then a Fast Fourier Analysis of the data is done to yield the tune. The BPM's will not be located in the same quadrant since they are a quarter wavelength away from the kickers. Rather than run cables around the ring to bring the data to one micro, the processing may be distributed over IOC's in different quadrants. One IOC will setup the hardware and kick the beam while another IOC measures the response and returns the data for processing.

This system will control and monitor the power supplies, monitor and setup the local electronics and measure the response. The electronics and measurement requirements are similar to the BPM requirements.

Beam Profile Monitoring

This system will determine the horizontal and vertical profile of the beam. It consists of two planes each with 64 channels. The hardware will have two high voltage supplies and magnets that must be controlled. A FTDR(1.2MHz) will be used to sample the data. The total data per system will be 2400 bytes per channel times128 channels, 153k bytes per pulse or about 10Mbytes per second. This will be a study device. The expected mode of operation is to sample data for several seconds and then read and process it by the computer.

The Beam Profile IOC must have some method for receiving the operating mode of the ring. This system will use Bit I/O boards to monitor the state of the electronics and set the channel gains. Accurate timing signals will be needed to sample the beam at the correct time. The power supplies will have a normal power supply control interfaces.

Data 64 channels Horizontal, 1000 samples per channel, 64,000 samples/pulse.

Data 64 channels Vertical, 1000 samples per channel, 64,000 samples/pulse.

Data for a number of pulses will be save in the IOC.

Beam Damper - A beam damper system will be installed in the Ring.A beam damper will be part of the diagnostics system. Bit I/O will be needed to set the state of the system and monitor the status. Digital output devices will be needed for feedback gain control. A 100MHz digitizer will be used to digitize the waveform data for display on workstations.

HEBT Diagnostics

Beam Loss Monitors - There will be 75 BLM's in the HEBT line. The injection beam dump will have two monitors. The controls for these systems will be similar to the controls for the Ring. The HEBT line has constant current pulse so gain change hardware and software is not required.

Current Monitor – There will be 3 Beam Current Monitors in the HEBT and 1 monitor in the injection dump line. The controls will be similar to the controls for the Ring.

Beam Position Monitors – There will be 33 beam position monitors in the HEBT plus 6 in the linac dump and 2 in the injection dump.

Harps – There will be two harps. Each system has 32 wire detectors in the horizontal and vertical plane. There will be one sample per pulse for each detector. A timing trigger will determine the data sample time. They will be controls to insert and retract the units.

Bunch Shape Monitors – There will be one bunch shape monitor. This system will be used to measure the detailed structure of the beam. To measure the 800Mhz structure requires a very fast digitizer. A 4GHz VXI digitizer will be used to acquire the data. Very high resolution (nanosecond) timing signals will be used to start data sampling and allow acquiring data on a portion of the beam.

Time of Flight Monitor – There will be one (1) time-of-flight monitor. This system includes 3 BPM monitors in the beam line. The RF phase or amplitude will be changed and the beam motion measured. The data from the BPM's will be processed to give time-of-flight data.

Wire Scanners – There will be four wire scanners. The wires will be stepped into the beam and measurements taken to determine the beam profile. Stepping motors will be used to position the scanners over a range of 5cm with 0.1mm resolution.

Wall Current Monitors – There will be two wall current monitors. Fast digitizers, (1.0MHz) will be used to give an indication of the beam profile.

RTBT Diagnostics

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Beam Loss Monitors – There will be 74 Beam Loss Monitors in the RTBT. The pulse is short and there is no need to sample data during the pulse as done in the ring. There will be status monitoring of the BPM radiation levels and setting alarm trip points.

Current Monitors – There will be two current monitors.

Beam Position Monitors – There will be 30 beam position monitors. The data will be sampled once per pulse.

Harps – There will be 3 Harps. These will be used continuously to give the beam profile. The IOC will process the data to determine beam motion and to alarm on out of limit conditions. Two units will be installed at one location for redundancy.

Wire Scanners – There will be 4 wire scanners in the RTBT. Stepping motor controllers will be used to position the scanners over a range of 15 cm with a resolution of .5mm.

BEAM PERMIT SYSTEM

The Beam Permit module is part of a system that allows the beam to be injected or can cause a beam dump. Some control systems have separate Beam Permit and Fast Dump systems. The Beam Permit system enables injection by the computer. The computer is expected to check that all injection parameters are within range before issuing a permit enable. The Fast Dump System hardware will cause the beam to be dumped and prevent further injection when an error is detected. The NSNS recommends using a combined system as used by RHIC. A detailed description is included in the references.[11]

The RHIC Beam Permit module is a VME board that accepts input from the computer or external signals and generates signals that enable the beam. An absence of the enable signal inhibits the beam. The Beam Permit system consists of a number of Beam Permit modules connected in series and configured so that all modules have to issue an enable signal for the beam to be enabled.

Systems that will use the Beam Permit system include Beam Position monitors, Beam Loss monitors, Vacuum, power supply, RF and safety systems. A failure in any of these systems will inhibit the beam.

The Beam Permit system requires a master crate and individual boards in local systems.

Some requirements for a Beam Permit system are:

- Software enable and disable of injection.
- Hardware disable of injection and beam dump.
- Fail safe. (Disconnection of cables inhibits injection.)
- Simple interface to a variety of equipment
- Notification to all IOC's on a beam dump. For the NSNS upon the recognition of an error all MADC's and other diagnostic devices must stop recording data until the data prior to the abort is analyzed.
- Continuous monitoring of the system.
- Distributed system.
- Time stamp of beam dumps.
- Fast response, a few microseconds to inhibit injection.
- Output signals to Extraction Kickers.
- Linac interface to prevent injection.

The present RHIC system meets all the above requirements but is designed to be used with other BNL VME modules, for example the RHIC timing system. An NSNS version of this system is proposed.

Timing System

[11] http://www.rhichome.bnl.gov/Hardware

Some portion of the timing system will be provided by ORNL. The following is a list of some functional requirements of the timing systems. Further discussions with ORNL will be necessary to determine which parts are to be provided by BNL and which by Oak Ridge. A timing system will be needed at BNL during the testing and integration stage.

Time-of-Day

Data read by an IOC will have a time stamp so that data read from different IOC's can be correlated. The Epics system has provisions for time stamping but VME hardware is needed to provide time data. Time stamping can be absolute time-of-day or a pulse number and a high resolution clock synched to the RF. Hardware at BNL and Los Alamos is available that can supply time-of-day to microsecond accuracy. RHIC has a RTDL system that can provide time data at lower resolution. The NSLS system distributes IRIG standard time data obtained from radio receivers to all IOC's. A time distribution system is needed. It's assumed that this function will be provided by ORNL.

RF Based Triggers

Some diagnostic systems measure information on each bunch in the ring. This requires very accurate timing signals that are synchronized to the Ring RF systems. The timing system must provide to each subsystem a very accurate reference signal for diagnostic and other devices. Where the subsystem needs many triggers each with a different delay, it's assumed they are produced locally.

Event Timing

An event timing system is often used in large accelerator timing systems. It allows distributing timing events or signals around the complex. With one cable many different triggers or can be distributed to nodes or hardware around the complex. IOC's can be interrupted and specific tasks can be enabled or inhibited. BNL will assume that a system similar to the RHIC timing system is in use at the NSNS.

Real Time Data Link

The Real Time Data Link (RTDL) is a single wire transmission system that distributes parameters to all IOC's in the control system. This is not normally considered part of the timing system but is closely related.. It is useful to have key parameters available in each IOC. The operations of the IOC may change as a function of global parameters. For instance if the current is high some diagnostic equipment should not be inserted into the beam or if in maintenance mode some error reporting could be turned off. A RTDL link is being considered for use in the NSNS control system.

Integrated Timing System

The timing system is an integral part of the control system hardware and software. In the RHIC system for example timing signals go to the Beam Permit, Utility modules, and MDAC modules. The Utility module looks for timing system faults. The Beam permit system must timestamp faults and report events to other IOC's. The MDAC needs time information for data tagging. Whatever system(s) is used at the NSNS it must be compatible with all the other hardware used in the control systems and meet the requirements above.

Testing at BNL

A timing system will be needed at BNL relatively early in the project for software and integration testing. The design of control and diagnostic hardware will depend upon the timing system specifications.

FRONT END COMPUTER (FEC/IOC)

The CPU to be used is yet to be determined. All laboratories will use the same CPU for ease of maintenance. Its assumed that the CPU will have functions,(i.e. Ethernet, Memory etc.) similar to VME boards used at BNL and in the various EPICS systems. Its also expected that present systems will not be used but newer systems with faster CPU's, more memory and 100MHz Ethernet will be the standard.

Some of the control system hardware described will be based on hardware used at RHIC and AGS. At BNL several boards have been designed and are proposed for the NSNS. Its possible that some modification of the hardware might be worthwhile to make an NSNS version of the boards minus some unneeded functions.

Each FEC consists of a VME crate, CPU board, Utility module, timing modules and battery backed up memory. In many systems a Beam Permit module will be needed. A functional description of the modules is given below.

Each IOC will also have other modules specific to the requirements for that system. The hardware required for each system will be determined by the group responsible for the subsystem(RF, Vacuum, etc.).

VME Crate

The NSNS will use the RHIC/AGS standard VME crate. The specifications call for a 750 watt power supply, cooling air plenum, five DC cooling fans with ball bearings, fan speed sensors, power fail detect sensor, slots for rear mounted transition modules and other features. The fan sensors are input to a utility module which will give an alarm on a fan failure. Fan failure causes overheating which can eventually can lead to board failure. Without monitors this may occur at inappropriate time and may be difficult to detect. The power fail detect sensor will alert the computer to a pending power failure with sufficient time to take action like saving key parameters in battery backed up memory, stopping motors etc. The power fail detect circuit insures that short term power failures do not leave the computer in a hung state by forcing a restart.

Utility Module

A utility module will be present in every IOC to do the functions below.

- Power Supply Monitoring
- Fan failure monitoring.
- VME crate temperature monitoring.
- Interrupt generation from external pulses.
- Remote reset of CPU.

. The monitoring of crate temperature, AC power, VME power supply voltages and fan failures will improve the reliability of the system by helping to detect potential problems before damage is done to equipment More importantly it may allow an orderly system shutdown(e.g. beam inhibit) and thus prevent beam dumps. IOC software will continuously monitor the above and report out-of-tolerance conditions.

Remote reset will allow restarting the computer from remote locations, for example the control room. This facilitates the installation of software modifications as new software can be loaded when a reboot is performed.

The interrupt function lets external triggers generate an interrupt to the CPU.

The above functions are provided by the RHIC utility module which will be installed in every IOC.

Extension Utility Module.

This module is used in slave VME crates to provide some of the same functionality as the Utility module provides to the IOC master VME. Slave crates are used when there are more VME modules than can be inserted into a standard VME crate or where I/O boards must be physically separated by long distances. The CPU and some I/O boards are in one VME chassis while other I/O boards are in slave VME chassis's. In such a case the CPU must be able to monitor the slave crates as well as the master crate. The Extension Utility module provides this capability. It will perform the functions below:

- CPU interrupts Power Supply Monitoring
- Fan monitoring
- Temperature monitoring

Diagnostic Data Channel Count Estimates

Ring Data

Beam Loss Monitors (80) (Read Data at 60Hz) (Sample Rate 100KHz)

System	# Channels	Samples Per Pulse	# For 1 Pulse	# Pulses	Total
TDR	80	100	8000	200	1,600,000
Power Supplies	8	7	56	200	112,000
Status	80	5	400		400
Setpoint	80	1	80		80
Readback	80	1	80	200	16,000
Gain table	80	4	320		40
Total			8936		**1,728,520**

Fast Beam Loss Monitors (8) (Read data at 60Hz.) (FTDR Rate 1/2MH.)

	# ITEMS	# SAMPLES PER PULSE	#FOR 1 PULSE	# PULSES	TOTAL DATA
FTDR	8	1200	9600	200	1,920,000
Power Supplies	8	6	48		
Timing	8	2	16		
Power Supply Setting Vs Time	8	40	320		
Control	8	4	32		
Total			10,016		?

Current Monitor (60 Hz Read) (Read Rate 100KHz)

DEVICE	#	#SAMPLES PER PULSE	#PULSES	
Gain control	1	4		
TDR	1	100	200	20,000
Timing	1	2		
Total		106		

(TDR is 100K Hz.)

Fast Current Monitor

DEVICE	#	DATA PER PULSE	# FOR SINGLE PULSE	# PULSES	TOTAL
FTDR		1,000,000	1,000,000	TBD	
Status	1	10	10	TBD	
Gain	1	4	4	TBD	
Calibration	1	4	4	TBD	
Total					

(Sampling rate is 1 GHz.)

Beam In Gap Monitor (Read 60Hz)

DEVICES	#	DATA PER PULSE		#PULSES
FTDR	1	1000		
Gain	1	2		
Timing	1	2		

Status	1	8		
Total				

Beam Position Monitor (60 Hz. Read)

DEVICES	#	DATA PER PULSE	# 1 PULSE	
Horizontal	48 x 2 = 96	1200	115,200	
Vertical	48 x 2 = 96	1200	115,200	
Status Data				
Gain Table	192	6		
Timing	96	2		

(Uses a FTDR, 1.2 MHz)

Fractional Tune Measurement

DEVICE	# DEVICES	DATA PER CHANNEL	# PULSES TO SAVE DATA	
Power Supply	2	10		
Status Bits	1	10		

(Correlation of Data in Different IOC's, One with VFTDR)

Beam Profile Monitoring (60Hz) (Data Rate 1.2MHz)

DEVICE	# DEVICES	#SAMPLES PER PULSE	DATA PER PULSE	CHANNELS PER DEVICE	# PULSES	TOTAL DATA
Vertical, FTDR	64	1200	76,800		200	
Horizontal, FTDR	64	1200	76,800		200	
Power Supplies	2			25		50
Status Bits	4	12				
Gains	4	8				
Power Supplies	4	10	40			
FTDR	4			12		
Total	146		153,640			